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A Computer-Based Demonstration of the Effects of Reward Bundling on Self-Control Exhibited by Children Identified as Impulsive

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ABSTRACT

A Computer-Based Demonstration of the Effects of Reward Bundling on Self-Control Exhibited by Children Identified as Impulsive

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Impulsive choice refers to the preference for a smaller-sooner (SS) reward over a larger-later (LL) reward when the larger reward would have been chosen at a longer delay to the choice pair; self-control is the inverse. Patterns of preference for impulsive alternatives can have adverse effects on delay discounting and self-control, especially when associated with addiction and disabilities. Although research exists showing the effectiveness of various methods for decreasing rates of delay discounting and shifting preference towards self-control (e.g. magnitude effects; progressively increasing delays), it may be beneficial to explore additional procedures that lead to successful outcomes. Therefore, the purpose of the current study is to extend and translate the basic literature on impulsive behavior to clinical populations by evaluating the effects of reward bundling on self-control using a computer-based model with individuals with disabilities.

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CHAPTER 1: Introduction

Self-control is defined as the selection of a delayed, large reinforcer over an immediate, smaller reinforcer; impulsivity is defined as selecting an immediate, small reinforcer rather than the large delayed alternative (Logue et al., 1986). In most aspects of our lives, we are required to make decisions that weigh self-control and impulsivity. Watch one more episode, or get more sleep before a long day at work? Buy a taco on the way to work each morning, or spend that money on a car payment each month? Exercise for 30 minutes or watch an episode of a show? When combined, these seemingly trivial daily selections and consumptions of reinforcers can lead to an enduring pattern of behavior that can influence finances, mental health, and physical health (Rung & Madden, 2018).

Self-control deficits have been commonly associated with many disabilities (e.g., attention-deficit hyperactivity disorder [ADHD]; developmental disorders). The ability to exercise self-control instead of impulsivity may not develop naturally, warranting targeted intervention. Extensive research has evaluated the importance of children developing self-control through delays to gratification, with implications for life-long motivation and control processes (Casey et al., 2012). Teaching self-control skills (i.e. toleration of delays to reinforcement) to individuals with disabilities may hold particular value in developing interventions for increasing appropriate behavior and decreasing inappropriate behavior, especially when the inappropriate behavior is characterized as impulsive. For instance, a child may be taught to raise their hand in class instead of yelling out for attention. As the environment changes (e.g., new peers in class, a different teacher, or home school) the contingency may weaken and a delay between response and reinforcement occurs. If the child engages in impulsive behavior, hand raising may decrease in favor of more immediate reinforcement such as negative teacher attention or conversation with peers; and both hand raising to gain attention appropriately and time on-task are jeopardized by the delay to reinforcement.

Applied work in self-control training has demonstrated positive results through procedures such as gradually increasing delays to the larger delayed reinforcer, or offering a distracting task during the delay. Schweitzer and Sulzer-Azaroff (1988) gradually increased delays to the larger reinforcer over many sessions with preschoolers identified as impulsive, shifting preference from the small immediate reinforcer to the self-control alternative for 4 of the 5 subjects. In a study on self-control and physical therapy exercise Dixon et al. (2003), a participant with acquired brain injuries was taught to engage in the physical therapy requirement during delays to reinforcement. The participant made choices between small immediate or larger delayed reinforcement contingent on performing the therapy exercise; subsequently, he was required to choose between a larger delayed reward with or without the therapy exercise with a progressive delay requirement. Results indicated that the participant shifted preference from the smaller immediate reinforcer to the larger delayed reinforcement option and the physical therapy requirement. Similarly, Binder et al., (2000) examined a progressive delay procedure in conjunction with intervening verbal activity for three preschoolers identified with ADHD. They found that offering a verbal rule of the contingencies was as effective as requiring a simple intervening activity in bringing about self-control in young children with ADHD.

Whereas self-control training focuses on treating behaviors of individuals in applied populations by adjusting environmental variables to shift preference towards less impulsive behavior, delay discounting broadly investigates the conditions under which human and nonhuman species subjects will devalue reinforcers by manipulating a wide range of tightly controlled variables. For example, many discounting studies with animals have examined choices between either different amounts of food (Mazur et al., 1987), sucrose (Freeman et al., 2011), or drugs and alcohol (Mitchell et al., 2006). With humans, rewards including hypothetical money, hypothetical food, and real monetary, food, drug, and health outcomes have been examined in relation to impulsivity (Rung & Madden, 2018). However, few studies have focused on measuring delay discounting outcomes in children (Staubitz et al., 2018).

Both areas of research have contributed greatly to our understanding of impulsivity, offering a wealth of evidence-based strategies. However, no research has shown lasting change in impulsivity for children with disabilities. Research examining interventions that impact tolerance for delays and maintenance of outcomes may yield significant clinical returns. Within delay discounting, there exists an area of limited study referred to as reward bundling (Ainslie, 1975), which has produced promising results in bringing about self-control in lab-based settings (Rung & Madden, 2018). Ainslie (1975) predicted that people may view their current choice as setting a precedent for future choice, and will choose to forgo a currently preferred alternative. Similar to the classic impulsivity/self-control choice paradigm, the participant is instructed to choose between a small amount of a reinforcer now or a large amount following some delay. Then, rather than receiving the selected alternative just once, the participant is "locked into" their selection and experiences the delay and reward multiple times before the choice is represented. To date, studies on the effects of reward bundling have been conducted only in tightly controlled settings either with nonhuman subjects, or with typically-developing adults using hypothetical monetary rewards or real rewards on computer-based programs.

For instance, Ainslie and Monterosso (2003) evaluated reward-bundling using sucrose solution for eight rats exposed to two conditions of intertemporal choice. In both conditions, the small-immediate reward amount was adjusted across sessions, and the large reward was delayed by three seconds. The rats showed greater preference for the large delayed reward when the selected reward was automatically delivered three times (i.e. bundled) than when it was selected singly and delivered after each choice. This data may demonstrate how subjects view their choices as predictive of future choices. Hofmeyr et al. (2011) evaluated whether adult smokers would be more likely to prefer the self-control choice if they were encouraged to view their current choice in this way by comparing responses to free-, suggested-, or forced- alternatives. Results showed that smokers' preference for the smaller-sooner (SS) reward alternative could be mitigated following repeated exposure to encouraged or forced repetition with the bundled rewards. Similarly, Kirby and Guastello (2001) evaluated the precedent effect and reward-linking effect with bundling and self-control. That is, do people view a current choice as setting a precedent for future choices, and do they respond to external influence to view the rewards as links in a larger chain of behavior. In Experiment 1 adults received real money, and in Experiment 2 adults received pizza. In both experiments, the majority of participants who made choices for sequences of rewards reversed previous preference and chose the larger delayed reward. That is, a series of rewards appeared to make a stronger impact on the self-control choice than rewards presented singly. Further studies that manipulate variables related to reward bundling, and show effects on self-control in applied populations will help to develop treatments that have lasting results.

Methods for self-control training and delay discounting may be combined and translated to offer a practical procedure to demonstrate the efficacy of reward bundling on impulsive behavior of individuals with disabilities. Environments used in basic experimental arrangements with animals, or those with typically developing adults operating advanced computer systems, have fewer complexities than those in applied human environments. With the opportunity to isolate variables, comes the difficulty of extending findings to more complex systems and the subtle variables at play. For example, previous literature on reward bundling has utilized mass-trial arrangements with sucrose to analyze rats' responses, or hypothetical delays in auction-based monetary programs for adult smokers, which would be ill-suited to implement with children. Further, translational research can be valuable for further isolating potential behavioral mechanisms identified in basic studies and allow for more circumspect investigation of potentially mitigating procedures before applying them to clinically relevant behaviors. In studies with persons with developmental disabilities, it has been shown that experiencing real delays and reinforcers can change the outcome of choice assessments (Staubitz et al., 2018). Therefore, the purpose of the current study is to extend and translate the basic literature on impulsive behavior to clinical populations by evaluating the effects of reward bundling on self-control using a computer-based model with individuals with disabilities.

CHAPTER 2: Review of the Literature

Impulsive choice refers to the preference for a smaller-sooner (SS) reward over a larger-later (LL) reward when the larger reward would have been chosen at a longer delay to the choice pair; self-control is the inverse. Delay discounting is the devaluation process used to understand the conditions under which organisms prefer one outcome over the other by describing the subjective value of a LL reward assessed over a range of delays. This nonlinear, often hyperbolic function, quantified by Mazur (1987):

$$V = \frac{A}{1+kD}$$

includes *V* as the discounted value of a LL reward amount of *A*, delivered following delay *D*. The steepness of the discounting curve is quantified by *k*. The hyperbolic function is defined by a reduction in the rate of devaluation with increasing delay, where value is discounted most steeply over short delays but flattens as delay length increases (Mazur, 1987).

Self-control deficits occur frequently in our day-to-day living. We may defect on allocating time to school or work assignments, eating healthy foods, exercising, or paying bills on time. While such choices do not always carry a significant weight with them, patterns of preference for impulsive alternatives can have serious impacts, especially when associated with addiction and disabilities (e.g. attention-deficit hyperactivity disorder, ADHD; developmental disabilities such as autism spectrum disorder, ASD). For example, research has found that individuals with ASD perform worse on measures associated with time discounting than healthy control counterparts (Murphy et al., 2017). Studies evaluating delay discounting and self-control typically pose a smaller-sooner reward against a larger-later reward to determine the conditions under which a subject will prefer to act impulsively or to show restraint. The experiment may present an arrangement such as: Would you prefer: (a) to receive one stimulus (e.g., a taco) today, or (b) to receive two stimuli (e.g., two tacos) in one week?; where the subject selects the option of highest value across a range of delays. For example, in one study (Kirby et al., 1999), heroin addicts and matched controls selected between smaller monetary rewards ($11-$80) available immediately and large rewards ($25-$85) available after delays (one week- six months). On average, heroin addicts' discount rates were twice those of controls (e.g., k=0.013 and k=0.025, respectively). Because they devalued the delayed rewards more rapidly (higher k value), they reflected a steeper discounting rate than the control group and exhibit lower self-control. A separate review of the literature on obesity and discounting found that 19 of the 25 studies positively associated discount rates with overweight, obesity, and unhealthy diets (Barlow et al., 2016). In order to improve such outcomes, research has attempted to shift preference from impulsivity to self-control by offering multiple choice presentations. In a study on the effects of magnitude and quality of reinforcement on choice responding during play activities, three boys with autism were presented with two concurrent response alternatives: (a) play in an area where a peer or sibling was located, or (b) play in an area without a peer or sibling. Results showed that after repeated exposure to conditions of equal and unequal reward magnitude and quality, all three subjects increasingly allocated responses from playing alone to playing in the area with the peer or sibling (Hoch et al., 2002).

While these studies have contributed widely to behavior management, real-life situations are often far more complex than contrived experimental scenarios (Bialaszek & Ostaszewski, 2011). Consequences of our choices are typically scattered throughout the future, rather than occurring concurrent with or immediately following those choices. In fact, people typically make choices based on future choices and consequences, yet most research on choice between immediate and delayed rewards has focused on single choices between rewards. Studies focusing on choices between individual rewards elucidate their effects in terms of individual scenarios, but less about the effects of larger sequences typical to naturally-occurring choice-making.

In order to approximate naturally occurring scenarios, researchers have begun conducting experiments on delayed sequences of rewards. The concept of reward bundling was originally introduced and described by Ainslie (1975) who suggested that one's current choice is predictive of, or sets a precedent for, one's future choices. By bundling a sequence of LL rewards together, the cumulative discounted value would exceed that of a bundle of SS rewards, resulting in a preference for self-control choices (i.e., Ainslie, 1975). Thus, rather than receiving a single reward following an SS versus LL choice trial, reward bundling entails selection of the SS or LL which results in multiple deliveries of the reward following the pre-specified delay. For example, one reward bundle may contain four SS rewards—the first delivered immediately, and the others in succession. When the person selects this SS reward bundle, he/she immediately gains the SS reward and then only the remaining three smaller rewards in the future (and not receiving any of the LL rewards) prior to another choice presentation. The other bundle option is composed of four LL rewards—the first delivered following an initial delay and the others following three subsequent, identical delays. The value of the LL bundle exceeds that of the SS bundle and the person is predicted to shift preference for the LL; an outcome confirmed in previous research on human decision-making (Kirby, 2006; Kirby & Guastello, 2001).

Individuals who tend to exhibit impulsive behavior in clinical populations may not view current decisions in terms of the larger sequences to which they typically belong, and could benefit from procedures that improve their likelihood of consistently choosing self-control. For example, the persistence of addiction is often associated with addicts' relatively greater valuation of the smaller-sooner reward (i.e. a steep discounting rate; Odum, 2011; Reynolds, 2006; Stein et al., 2013). By manipulating the total nominal value of a given sequence of delayed rewards, the steepness of discounting can be altered to reduce the level of impulsivity, providing greater opportunity for self-control choices that are ordinarily more adaptive (Bialaszek & Ostaszewski 2011).

Results of recent research on both delay discounting and self-control training have outlined procedures that reduce impulsive behavior across species and settings (i.e., Dixon, 1998; and Rung & Madden, 2018, respectively). Rung and Madden (2018) reported that the largest and longest-lasting effects on improved self-control were produced by learning-based manipulations such as reward bundling; yet there is insufficient evidence for this procedure's application with clinical populations, which is arguably due to the dearth of research in this area. As research continues to evaluate the components in choice and reward arrangements on self-control, there are no known systematic reviews of the literature that focus on sequences of delayed rewards. Therefore, the purpose of this review is to evaluate literature that has explored additive effects of sequences of delayed rewards on self-control using reward bundling.

Method

An online search was conducted for studies published in peer-reviewed English-language journals of the University of Texas at Austin library using the EBSCO database. Education Resources Information Center (ERIC), medline, and psycINFO were then searched with the terms "reward bundl*"; "parallel discount*"; "rewards AND choice behavior"; "discount* AND self-control"; and "multiple rewards". This initial search yielded 473 articles, and after reviewing titles and abstracts, seven met criteria for inclusion. Next, a forward and backward search was performed on the references in the included papers, and any identified in the delay discounting literature that had multiple experiments manipulating an independent variable on self-control. Two further studies were identified. Finally, a hand-search was conducted of the *Journal of the Experimental Analysis of Behavior* and *Behavioural Processes*, and the identified nine studies were entered into Google Scholar's search option and the "cited in" function was engaged which resulted in identification of 348 additional studies. Neither of these searches identified further studies for inclusion, leaving the total number of studies at nine.

Inclusion Criteria

Studies were included if they (a) utilized a valid, empirical-based experimental design; (b) were published in an English-language, peer-reviewed journal; and (c) evaluated the effects of reward bundling or sequences of rewards. Reward bundling was defined as delivering multiple delayed small or large reinforcers contingent upon respective choice for the short or long delay in any of the procedures evaluating choice-making.

Exclusion Criteria

Non-intervention and non-empirical-based studies (e.g., reviews, qualitative studies, biomedical research) were excluded by inspecting titles and abstracts. Studies were also excluded if they (a) examined preference for small versus large reward using sequences of rewards without manipulating variables to shift preference towards self-control; (b) evaluated magnitude and/or duration effects within sequences rather than the bundle's/sequence's effects; (c) used forced-choice or adjusting amount procedures without analyzing the effects of a bundle on choice; (d) did not familiarize the organism to all of the reward alternatives (see Mazur, 2001); and (e) temporal clumping (e.g., Stephens et al., 2006).

Results

Of the nine studies that met criteria for inclusion, four studies appeared in *Behavioural Processes,* three appeared in the *Journal of the Experimental Analysis of Behaviors,* one appeared in *Addiction,* and one appeared in *Journal of Experimental Psychology: Applied*. All of the studies were published between 1990 and 2013. Seven of the studies focused primarily on reward bundling or sequences of delayed rewards, and five of the studies focused on parallel discounting. Results are discussed in terms of (a) subject characteristics; (b) independent variables; (c) experimental arrangement; and (d) outcomes.

Subject Characteristics

Four studies included human subjects (i.e., college students), four included rats, and one included pigeons. Overall, study subjects included 206 college students (93 males, 123 females), 53 rats, and 3 pigeons. All but one of the studies (i.e., Bialaszek & Ostaszewski, 2011) utilized real (rather than hypothetical) rewards. College students received rewards in the form of cash, gift certificates, or food; and rats and pigeons received food (See Appendix, Table 1).

Independent Variables

Self-control was a dependent variable for all nine studies reviewed. However, the studies varied on the secondary dependent and independent variables of interest. Seven of the studies evaluated the effects of bundling sequences of delayed rewards on preference for a SS or LL rewards (i.e., Ainslie & Monterosso, 2003; Bialaszek & Ostaszewski, 2011; Hofmeyer, Ainslie, Charlton, & Ross, 2011; Kirby & Guastello, 2001; Mitchell & Rosenthall, 2004; Shull, Mellon, & Sharp, 1990; and Stein et al., 2013). Four of the studies evaluated parallel discounting as a model to better understand responses to sequences of delayed rewards (i.e., Bialaszek & Ostaszewski, 2011; Brunner, 1999; Kirby, 2006; and Mitchell & Rosenthall, 2004). Three studies evaluated magnitude effects of preference for SS or LL alternatives (i.e., Bialaszek & Ostaszewski, 2011; Mitchell & Rosenthall, 2004; Stein et al., 2013). Two studies compared explicitly linking the choice to the future occurrence of reward to no information about their choice (i.e., Hofmeyer et al., 2011 & Kirby & Guastello, 2001). Hofmeyer et al. (2011) compared forced-linking (i.e., subjects were explicitly told what would happen in the future based on their current choice for an alternative), suggested-linking (i.e., subjects were told that each time they made a choice, it would indicate how they would choose in the future), and free-linking (i.e., subjects were given no information about how their choice affected the future). Kirby and Guastello (2001) compared imposed-linking (i.e., the subject was informed in the choice phase that their current choice would commit them to a series) and free-linking (i.e., the reader supplied any perceived linkage between current and future choice). Brunner (1999) evaluated improving versus worsening sequences of rewards by increasing or decreasing the delays within the sequence. Shull et al., (1990) used terminal link chain schedules to evaluate the effects of the delay to the first delivery on choice for sequences of rewards, as well as changing the delay in the middle of the sequence to assess whether animals were sensitive to the temporal arrangement. Lastly, Mitchell and Rosenthall (2004) evaluated the effects of a rich versus lean delay context (in a manner similar to foraging theory) on delay discounting.

Experimental Arrangement

Adjusting Amount. All of the studies involving human subjects utilized a computer-based auction program centered on an adjusting amount procedure in which choices were adjusted on each trial to reflect the indifference point at which the subject would find either choice alternative to be equally valuable (see Mazur, 1987; Richards et al., 1997). In an adjusting amount procedure, the amount of reward for the SS option is increased or decreased until the smallest immediate amount is chosen over the LL option. When the immediate amount reaches a level at which the subject perceives it to be equivalent to the delayed alternative, choices should be selected in an alternating fashion between the immediate and delayed alternatives indicating that the subject perceives the choice options to be subjectively equivalent. The indifference point is obtained when the size of the immediate reward stabilizes. Subjects were trained on the auction procedures prior to data collection to ensure that the results reflected subjects' true valuation of the alternatives. Two of the studies adjusted the SS amounts in 10 cent increments, and the other two by taking half of the nominal sum of the rewards in the sequence. Kirby and Guastello (2001) asked subjects to report their present value of $8.80 rewards over 15 delays, ranging from 1-43 days over 15 computerized auctions. The subjects adjusted their present value by 10 cent increments until they determined the statement to be true, confirmed by clicking a "seal bid" button. The subject would then confirm indifference between the two rewards. For example, if the present value on a trial was $6.40, the subject would be asked "Would you rather get (A) $6.40 today or (B) $8.80 in 7 days?" The subject could select (A), (B), or "about equal". If (A) was preferred, the subject was asked to lower the reported value, and if (B) was preferred, then they should increase the value. When the subject expressed indifference, the reported value was accepted and a new trial would begin. The authors used each reported value to estimate a delay-discounting rate for that trial, and the median rate across trials to choose appropriate delays for the second part of the procedure. This procedure was repeated with bundled sequences of rewards in other conditions, then with pizza as the reward in the second of two experiments (Kirby & Guastello, 2001). Kirby (2006) similarly adjusted the SS reward amount at 10 cent increments, but for cash and food certificate rewards. In Bialaszek & Ostaszewski (2011) and Hofmeyer et al. (2011), if the [fixed] LL alternative was chosen, the SS amount increased by half of the difference between the total nominal value of the delayed sequence and the preceding value of the immediate reward. For example, trial (a) offers $2 today or $10 in 7 days, and the subject selects the delayed amount. Trial (b) would then offer $4 today or $10 in 7 days (($10-$2)/2). Two of the studies using rats also utilized an adjusting amount or delay procedure by increasing or decreasing the amount of sucrose available in the next trial based on the previous choice, or by increasing time to the fixed reward amount. Mitchell and Rosenthall (2004) started each session at 75 l of sucrose solution for the SS reward (A). Selecting the delayed reward lever increased *A* by 10% for the next trial. Selecting the immediate reward lever decreased *A* by 10% for the next trial. The amount of the delayed alternative remained at 150 l for all sessions. This procedure was repeated across five delays, then again for the reward bundling conditions. Stein et al. (2013) used an increasing-delay procedure in which delay to receipt of the fixed SS or LL amounts increased across trials. The three studies that did not utilize the adjusting delay employed forced- and free-choice trials (Ainslie & Monterosso, 2003; Brunner, 1999; Shull et al., 1990) and terminal link chain schedules (Shull et al., 1990; see below).

Forced- and Free-Choice Trials. Four of the studies (Ainslie & Monterosso, 2003; Brunner, 1999; Shull et al., 1990; Stein et al., 2013) utilized free- and forced- choice trials during training and intervention to first expose the subjects to the contingencies of the procedure, then to assess preference and ensure sampling of the alternatives to confirm that choice was not arbitrary or related to extraneous variables.

Ainslie and Monterosso (2003) scheduled a block of four forced-choice trials between blocks of four free-choice trials in the stand-alone condition. During a free-choice trial two levers were extended, one accompanying the SS reward delivered immediately, and the other accompanying the LL reward delivered following a 3-s delay. The LL amount remained fixed throughout the experiment, and the SS amount varied based on random assignment by the researchers (rather than by the subject choice immediately preceding it). Thus, although the procedure was designed to determine the amount at which the two alternatives would be equally preferred, the procedure was different from adjusting the amount because the animal did not control the varying amount of the SS reward via choice. The procedure for the bundled condition was identical to the stand-alone condition; however, without further presentation of the levers, the chosen reward followed two more cycles of delay and reward. The investigators presented the stand-alone and bundled choices in an ABBA design over 72 sessions as follows: (A) three sessions of stand-alone choice with the six immediate reward amounts presented in descending order; (B) three sessions of bundled choice for the immediate reward amount in ascending order; (B) three sessions of bundled choice for the immediate reward amount in descending order; (A) three sessions of standalone choices for the immediate reward amount in ascending order.

In Brunner (1999), after two forced-choice trials with each lever, the rats were allowed to choose between both levers in four choice trials. Experiment 1 did not address reward bundling. Experiment 2 tested preference for unequal reward amounts in ten conditions providing either two or six pellets delivered by pressing the associated lever. Delay to the first pellet varied in conditions, and some conditions were repeated with the assignment of sequence to lever reversed. In one of the conditions, the four middle pellets of the 6-pellet sequence were removed (resulting in a two versus two choice) to test sensitivity to the delays. Experiment 3 was similar to Experiment 2, with the exception of increased delay to the larger sequence and to the second pellet in the shorter sequence.

Upon completion of choice-training trials to food receptacles containing either 1 or 3 pellets, Stein et al. (2013) began sessions with six forced-choice trials in each 20-trial block in which only one receptacle was lit following a lever press. Impulsive choice was then assessed (pretest) using a within-session increasing-delay procedure in which the delay to the three-pellet alternative increased across trial blocks from 0, 5, 15, and 45 s. Terminal data were taken from the final six sessions. For the reward-bundling phase, rats were matched into triads based on their results in the terminal impulsive-choice pretest sessions, then randomly assigned to bundle-size 1, 3, or 9. Bundle-size 1 group served as a control. The rats emitted choices during 18 trials per session, with the first four trials consisting of forced-choice, followed by 14 free-choice trials. Lastly, a posttest of impulsive choice was implemented by repeating the pretest procedures.

Shull et al. (1990), intermixed choice- and forced-trials during sessions. In free-choice trials, both keys were available in the initial link, and a peck to one started the terminal link. A single peck to the left key in the terminal link changed its color to green for 120 s and darkened the right key. After 4 s of green, food was presented independent of responding and the rest of the interval elapsed, with a second hopper delivery at the end. If the pigeon pecked the right key, its color changed to red and the left key darkened. 20 s later, the hopper was presented independent of responding; then presented again after 40, 60, and 80 s, respectively. After the fourth hopper presentation, food was not available again until the end of the 120-s period, then the hopper was presented once more and the next initial-link period began. A forced trial consisted of lighting only one of the two keys during the initial link, and pecks to the dark key had no effect. Each session consisted of a combination of eight forced-choice (four to each key) and 12 choice trials, presented as: two forced followed by two choice for four blocks, then one forced followed by two choice for four blocks. The delays were held constant for a block of sessions, but varied across sessions to alter the relative values between the two terminal links.

Outcomes

Outcomes are reported in terms of improvement or lack of improvement on measures of self-control, goodness of fit to the parallel discounting model, magnitude effects, and generalization and maintenance.

Improved Self-Control. All nine studies reported improvements on measures of self-control. With regards to reward bundling, Ainslie and Monterosso (2003) found that bundling SS and LL reward choices resulted in a greater preference for LL rewards than when choices were made singly. Further, bundling effects were more robust in the AB condition than the BA condition suggesting general increased tolerance for delay over course of the experiment because of how time affected the increased preference for the bundled alternative in the first half (AB), and was attenuated in the second half (BA). Similarly, Mitchell and Rosenthall (2004) found that the presence of multiple delayed rewards increased the subjective value of the delayed option, as shown by the increases in the indifference points. Both Bialaszek and Ostaszewski (2011) and Stein et al. (2013) reported that increasing the value of the delayed sequence of rewards changed the steepness of temporal discounting and modified the level of self-control because the delayed sequences of large rewards were discounted less steeply than the delayed sequences of small rewards. Stein et al. (2013) also showed that as delays increased, there was a significant decline in the percent choice for the LL reward in the reward-bundling phase. A significant main effect with bundle size was shown only for bundle-size 1 and 9 groups (i.e., the largest and smallest groups). The authors also found that as the number of SS and LL rewards that are bundled together is increased, there is an increased preference for the LL reward bundle. Post-bundling preference for the LL reward increased above pretest levels for bundle-size 9 group only. Using terminal-link schedules to evaluate the effects of delayed sequences, or reward bundling, Shull et al. (1990) determined that the overall choice patterns matched the additive function that each food delivery in a sequence contributes to the total value of that alternative. Delay to the first delivery did not dictate preference for the SS versus the LL sequence. Also, pigeons chose the alternative that maximized reinforcement even at changing delay contexts, reflecting sensitivity to the sequence arrangement. Even when the delay to the first delivery of both alternatives was very short (i.e., the two-food sequence was shorter than the five-food), the birds selected the 5-food alternative which supplied greater reinforcement despite longer delays. The patterns of choice were predictably inconsistent when choice was closer to indifference, showing true valuation of the alternatives.

Hofmeyer et al. (2011) and Kirby and Guastello (2001) evaluated how salient the reward bundling information needed to be for humans to make less impulsive choices. The two experiments showed that the more salient the information on their choices was, the more likely they were to choose the LL reward. Further, Hofmeyer et al. determined that smokers were more likely to select LL reward in the suggested and forced conditions than they were in the free condition. Further, the probability that smokers selected the LL rose across repeated trials in the experiment. Non-smokers, on the other hand, did not display sensitivity to the experimental conditions, and did not significantly adjust their behavior over time. Some subjects from all groups selected less impulsive choices than they had during baseline, where preference for LL rewards was zero by design. Among smokers, there was a significant increase in the proportion of subjects selecting the LL reward between the free- and forced-choice conditions (30% & 100%, respectively), and the suggested and forced-choice conditions (45% & 100%, respectively). Comparing smokers to nonsmokers across the experimental conditions, the authors found that in the forced condition, a significantly higher fraction of smokers selected LL than did nonsmokers. That is, when they were able to pre-commit to later choices, they abandoned their baseline preferences for SS rewards at a markedly higher rate than non-smokers. Kirby and Guastello (2001) similarly observed that alerting people that their current choice influences future choices was more effective than not giving them any information. In the first experiment evaluating money as a reward, a third of the subjects in the free-linking condition selected the LL reward when they were told that the choice was the first in a series of similar choices, even though they had previously chosen the smaller reward on a trial with a 1-day-shorter delay to the larger reward earlier in the session. The effects were much higher in the imposed-linking condition, where all but one of the subjects chose the LL reward. The suggested-linking condition yielded an intermediary level of effects, potentially indicating that people can be provoked to view their current choices as setting a precedent for similar future choices. Percentages were significantly above zero in both the imposed-linking and the suggested-linking conditions when pizza was evaluated as the reward in the second experiment. However, in the free-linking condition, there were no significant effects. The proportion of subjects that preferred the series of larger rewards in the imposed-linking condition was significantly greater than in both the suggested-linking and the free-linking conditions, and the proportion in the suggested-linking was significantly greater than in the free-linking.

Data from Kirby (2006) provided no evidence of a strong preference for uniform choice, and increasing the internal delay decreased the value of the bundle. There was a smaller effect size for varying only the middle of the three delays compared with varying the final two delays for both money and food bundles. Brunner (1999) found that in general, the rats preferred the larger-later alternative, despite the short delay (e.g. 0, 1, or 2 s) to the first of the smaller-sooner alternative programmed in some conditions. Both lengthening the delay to the first reward of the smaller-sooner alternative, and decreasing the delay between the larger-later alternative increased preference for the larger-later alternative. Removing the middle four pellets in one of the conditions significantly increased preference for the immediate reward sequence (as opposed to the now equal magnitude, but more delayed sequence). Further, preference favored the small immediate alternative whenever the large delayed alternative was sparse and delayed.

Mixed Findings. When outcomes were relatively large, the results of Bialaszek and Ostaszewski (2011) indicated that a single reward was discounted less steeply than the sequence of a total nominal value equal to the single reward; suggesting that people prefer sequences with an overall greater nominal value, but the possibility of choosing a single large reward was sometimes as preferable as obtaining the same amount spread over an extended period of time. Bialaszek and Ostaszewski (2011) also found that in 55% of cases, the single SS reward was discounted less steeply than a sequence of small rewards, and in 65% of cases, the single large reward was discounted less steeply than a sequence of large rewards. In Brunner (1999), there was an almost exclusive preference for the sequence that offered an immediate pellet for the condition in which time between pellets was long. When time between pellets was shorter, group preference was not significantly different from indifference due to both variability between rats and non-exclusive choices. In Kirby (2006), two subjects did not discount at all over the range of delays that were used, and two subjects in each experiment differed from the distribution by appearing to value the triads less than they valued the sums of the component rewards. Lastly, Stein et al. (2013) found that the medium (i.e., bundle-size 3) group effects were not significant from the large or small group, or from zero (recall that only the largest, bundle-size 9, differed significantly from zero and from bundle-size 1 and the control).

Goodness of Fit to Parallel Discounting Model. Five of the nine studies reported on goodness of fit for the data to a particular discounting model, five of which evaluated parallel discounting and found it to be the most appropriate model. In both conditions of Bialaszek and Ostaszewski (2011), the parallel model was well fitted to both group and the individual subjects' data. The results of Brunner (1999) were in qualitative agreement with the parallel model with a small value of the discounting constant *k*, which implies that rats did not discount very sharply and were willing to wait for the option with more reinforcers. Kirby (2006) indicated that sequences of money and food rewards were discounted much as one would predict from additive, parallel discounting of their component rewards, though there may have been a subset of individuals who valued sequences less than the sums of their component rewards. In addition, noise in the data remained unexplained, and it is possible that the model could be improved by taking magnitude effects and sequence effects into account.

Mitchell and Rosenthall (2004) determined that multiple delayed rewards increased the value of the delayed alternative, indicated by the increases in the indifference points. This increase was well fitted to the parallel model of discounting. However, there were some data points not well-explained by the model. For instance, a single reinforcer delivered after a delay of 16 s had subjective value to the rats, but, in the bundled-16 condition, the addition of a reward with a 16-s delay did not increase the value of the delayed reward alternative by an appreciable amount. That is, the indifference points in the bundled-16 condition did not differ from those in the single reinforcer condition with the addition of this long delay. As a result, they were significantly lower than predicted by the parallel model. It is possible that when the delay to the rewards or the inter-reinforcer interval is long relative to other experienced delays, the parallel model becomes less able to describe the data satisfactorily.

Ainslie and Monterosso (2003) did not report on the parallel discounting model, but instead the hyperbolic discounting model. The amount of immediate reward that was equally preferred to a fixed reward quantity delayed by 3 s was significantly greater in the bundled condition than in the stand-alone condition; consistent with: (a) temporal discounting occurs according to a hyperbolic function; and (b) the value of multiple rewards occurring at different delays is roughly the sum of the discounted values of each of those rewards individually.

Magnitude Effects

Four of the nine studies reported similar results on the presence of magnitude effects in experiments on reward bundling and self-control. There was a significant effect of reward size on the indifference point and a significant interaction between reward size and delay reported by both Mitchell and Rosenthall (2004) and Stein et al. (2013). Magnitude effects were also present in the discounting of sequences of delayed rewards of same and different amounts in Bialaszek and Ostaszewski (2011). Single SS rewards were discounted more steeply than single large rewards, and sequences of small rewards were discounted more steeply than sequences of large rewards. Ainslie and Monterosso (2003) did not initially designate magnitude effects as a variable under evaluation, but nevertheless stated that amount was a significant predictor of which alternative the subjects would choose (i.e., if the SS was large, they were less likely to select the LL).

Generalization and Maintenance

Two of the nine studies (i.e., Ainslie & Monterosso, 2003 & Stein et al., 2013) measured generalization and/or maintenance of the effects of reward bundling on self-control. Ainslie and Monterosso (2003) reported that unbundled conditions following the bundled conditions tended toward increased self-control, but did not report data for how long this lasted, nor to what extent. Stein et. al, (2013) evaluated lasting bundling effects using a pre- and post-test model. When choice for unbundled rewards was assessed following the reward-bundling phase, only the scores between the largest and smallest (i.e., bundle-sizes 1 and 9 groups) were significant, and only bundle-size 9 group differed significantly from zero. These results indicated that the group that experienced the largest bundle continued to allocate choices to the delayed reward. The seven remaining studies did not report any data in regards to the lasting effects of sequences of delays on self-control.

Discussion

The nine studies reviewed provide evidence for reward bundling as an effective procedure for increasing self-control, and that the results of such procedures are well-explained by the parallel discounting model. Subjects were more likely to allocate responses to the delayed rewards when they were presented in sequences than when they were presented singly. There is also evidence to support the use of the adjusting amount and forced-and free-choice procedures within reward bundling. The adjusting amount reflects the subjects' true valuation of the choice alternatives, and the forced- and free-choice trials provide a framework for exposing the subjects to the contingencies of the conditions, and allow investigators to assess preference and ensure sampling of the alternatives. In the context of this review, self-control refers to choices that reflect a globally more valuable behavior pattern. Although a SS reward may be preferred over a LL reward in isolation, choosing the SS reward could disrupt a pattern of future choices for the larger reward, and that cost could outweigh the immediate preference for the SS reward. Therefore, bundling series together may increase choice for the larger reward by placing choices within a context that choosing the smaller reward would disrupt that pattern for larger rewards (Kirby & Guastello, 2001).

All five studies evaluating parallel discounting found it to be the most appropriate option for modeling sequences of delayed rewards. However, the authors noted that there were some delays for which the model could not explain well, raising the need for a new or improved model beyond parallel discounting that can take such data into account. Kirby (2006) suggested that although sequences of money and food rewards were mostly predicted by an additive, parallel discounting model, some noise in the data remained unexplained, and it is possible that the model could be improved by taking magnitude effects and sequence effects into account. One suggestion for how to conceptualize the patterns of responding is the foraging perspective: that animals evaluate alternatives by considering the overall richness or leanness of the environment experienced in the recent past (Mitchell & Rosenthall, 2004). Future research is needed to understand these effects and their fit to discounting models.

Four of the studies provided evidence for the presence of magnitude effects in reward bundling. Typically, in order for there to be a significant increase in preference for the LL reward over the SS reward, the subject started with an elevated discounting rate, and/or the sequence needed to be long with a high number of reinforcers. Bialaszek and Ostaszewski (2011) reported that single rewards were sometimes discounted less steeply than the sequence, suggesting that subjects preferred sequences with a greater overall nominal value, but could allocate choice to a single larger reward not spread over time. Stein et al. (2013) found that the mid-size (i.e., bundle-size 3) group effects were not significant, and only the largest bundle size (i.e., bundle-size 9) differed significantly from the small bundle and the control. Generally speaking, a long sequence of rewards has a higher overall nominal value than a short one, but further research is needed to verify the degree to which reward-bundling effects are independent of magnitude effects. Future studies should address the discounting of delayed sequences of same and different overall nominal values.

Future translational studies should evaluate the effects of reward bundling on self-control behavior to benefit clinical populations such as individuals with ASD and developmental disabilities due to the nature of the procedures, and because evidence here indicates that bundling is most useful for discounting rates that lie close to indifference (i.e., an extremely high discounting rate is not required in order to experience effects). Outside of delay discounting, the applied literature on self-control training has shown supporting evidence for intervention components such as the manipulation of task requirements, rules, magnitude effects, and progressive time delays to improve self-control of children with disabilities (Gadaire et al., 2014). Such evidence-based treatment components could be combined with the procedures for reward bundling outlined in this review to further improve treatment outcomes and improve efficiency of implementation. For example, the adjusting amount procedure within reward bundling could provide information about the true value of rewards when adjusting magnitude of reinforcement, or help determine the appropriate number of task requirements to then shift preference towards the self-control alternative. Simplified versions should be adopted in order to analyze choice for those that do not operate a computer program. Further, requiring minimal instruction, interventionists could intersperse free- and forced-choice trials of bundles of rewards by presenting the options singly then together to orient the subject to the choice arrangement then assess preference under self-control training conditions. The free-, suggested-, and forced-linking conditions could be incorporated into rule-based interventions to investigate whether the salience of the reward arrangement reduces the number of teaching trials needed to shift preference towards self-control. If the choice-maker is reminded (or reminds him or herself) of the recurring nature of his or her choices and the different possible patterns of future outcomes, he or she may be encouraged to view the current choice as predictive of future choices (Kirby & Guastello, 2001).

In practice, the flexibility of implementing procedural components together or separately for reward bundling in self-control training is arguably a strength. For example, practitioners can use free- and forced-choice trials with or without the adjusting amount procedure, use the suggested- or free-linking conditions, or adjust the magnitude of reinforcement via adjusting amount, and reasonably expect at least small outcomes in treating impulsivity. In research, however, this could be viewed as a limitation as there is a not a conclusive body of evidence showing which components are most valuable in shifting preference towards self-control. Future studies are needed to determine which components are most valuable under various experimental conditions. In regards to working with individuals with disabilities, teaching self-control may prove particularly valuable in executing interventions that increase appropriate behavior and decrease unwanted behavior (Dixon et al., 1998). Identifying and treating behavior in individuals considered to be impulsive, using a procedure such as reward bundling, could have collateral impacts on skill development in other areas. If an individual becomes more capable of tolerating delay to reinforcement via accepting the larger-later reward, they may more readily respond to academic interventions, for example. Future research is needed to examine the potential for reward bundling to teach self-control as a skill that maintains following the removal of the programmed procedure. Stein et al. (2013) reported that when the bundling procedure ended, subjects in the largest bundle-size group continued to allocate responding towards the LL alternative. Two other studies (i.e., Ainslie & Monterosso, 2003; Hofmeyer et al., 2011) also reported that preference for the LL reward persisted following treatment, albeit without data on the conditions under which it continued. It can be challenging for practitioners with limited training in behavior modification to consistently implement procedures for extended periods of time, so identifying a procedure that maintains following a single intervention would provide an important opportunity for facilitating lasting behavior change. In the study by Hoch et al. (2002) teaching a child with autism to play with siblings and peers rather than alone, such lasting change would be meaningful for families or teachers as they build on communication and social skills. Extended further, if reward bundling could shift lasting preference for self-control, future research should evaluate the procedures under a relapse paradigm to determine whether such outcomes could persist under extinction.

Limitations to this review include studies potentially missed during the search, the variety of statistical models used to analyze results, and limited information on where reward bundling and parallel discounting fit into the larger picture of delay discounting and self-control. Systematically identifying studies for review proved difficult due to the lack of unifying terminology in the literature. Different languages are used to describe the procedures for discounting sequences of rewards as there is no single accepted terminology. While "reward bundling" was common, some authors implemented the same procedures either using similar, less specific language, or while examining a different variable within self-control or delay discounting meaning they wouldn't explicitly use such keywords (i.e., Brunner, 1999; Kirby, 2006; & Shull et al., 1990). Though it could be argued that the search procedure was thorough, there is potential that studies were not captured based on terminology. Secondly, a wide variety of tasks, reward amounts, delay durations, and associated dependent measures were studied in the reviewed experiments which could be differentially sensitive to experimental manipulations. There were also multiple statistical models used to analyze the data reported in the studies, all of which limits the opportunities for comparison and replication of results in this review and in future studies. Hence, future studies should attempt to reconcile terminology and statistical models in order to improve wider understanding of reward bundling and parallel discounting. Lastly, there is limited evidence available to draw conclusions about where reward bundling falls within the larger picture of delay discounting procedures with the exception of a recent review by Rung and Madden (2018). The authors report reward bundling as a learning-based approach that produces large and long-lasting reductions in delay discounting when compared with procedures from nine categories of experimental manipulations including clinical interventions, Episodic Future Thinking (EFT), framing, perspective taking, priming, cueing, context, learning-based approaches, and environmental enrichment/deprivation (Rung & Madden, 2018). While the results of the current review and the review by Rung and Madden (2018) show evidence supporting bundled sequences of delayed rewards as a procedure to improve self-control, much of the work has been conducted in controlled laboratory settings. Future research should continue to investigate such manipulations in laboratory settings with human and nonhuman subjects in order to refine methods, and extend work to clinical settings in order to evaluate efficacy and generalization with applied populations.

Rationale for the Current Study

The lack of data informing interventions that bias preference for self-control choices over impulsivity in children with disabilities informs the rationale for the current study. While some evidence exists for self-control training in children, no research has shown lasting preference reversal in young individuals with disabilities, despite the significance of children struggling with impulse control. The current study seeks to implement a computer-based demonstration of reward bundling to assess the potential for lasting bias in preference for self-control choice alternatives in children with disabilities.

CHAPTER 3: Method

Participants and Setting

Participants were included in the study if they exhibited (a) impulsive responding as indicated by caregiver report, (b) a vocal communication repertoire and early reading skills, (c) minimal challenging behavior elicited by tolerating delays to reinforcers, (d) previous experience with video games and/or computer-based leisure, and (e) limited training in self-control (including previous instruction to "wait" for extended periods of time). Prior to participation in the study, caregivers were asked to report a brief medical history including a list of current medication schedules and diagnoses.

Table 2 displays characteristics of the eight participants including pseudonym, gender, age at time of study, diagnosis (as reported by parents), and current medications at time of study. Sessions for four of the participants were terminated and excluded from the results of the study because they did not exhibit impulsive behavior during Choice Baseline 1, and instead demonstrated preference for the self-control alternative. Sessions for one participant were terminated and she was excluded from the study because she did not demonstrate preference for the small reward during Choice Baseline 2, when both the small and large alternatives were available immediately. The three participants included in the results of the study were identified as males, aged 5-17, are listed in the top panel of Table 2.

Table 2

Participant Characteristics

Participant	Gender	Age	Ethnicity	Medications	Diagnosis
Included					
Daryll	Male	16	Asian, White	None	ADHD, ASD, Combined type and intermittent explosive disorder
Martin	Male	5	White	None	None
Scotty	Male	17	White	Aptensio, Gabapentin, Lexipro, Divloprex, Valum	ADHD, ODD, Bipolar disorder, ASD
Excluded					
Kali	Female	16	Asian	None	ASD
Rose	Female	8	Black, Hispanic	None	ASD
Erin	Female	9	Hispanic	Concerta	ADHD
Clay	Male	6	White	None	None
Gavin	Male	11	White	Leucovorin	ADHD, ASD, ODD

Note. ADHD= Attention Deficit Hyperactivity Disorder; ASD= Autism Spectrum Disorder; ODD= Oppositional Defiant Disorder

Apparatus

Materials included a computer in both the client's and interventionist's home with Zoom teleconferencing software to provide a means of communication and allow the researcher to share the game rather than require the participants to download and operate any of the technology. Participants were asked to sit at a desk or table in a low-traffic area of the home with minimal access to outside activities or other people. The reward bundling program was built using Pygame software. The software is a game-based interface that includes floating balloons holding gifts as stimuli. The user launches rocks from a slingshot at the balloons by pressing keys on the keyboard. When the participant successfully hits a balloon with a launched rock, corresponding delays are implemented and corresponding points are assigned.

Experimental Design

The experiment employed a concurrent operant design (Brower-Breitwieser et al., 2008; Mitchell & Rosenthall, 2003; Shull et al., 1990). Choice trials in the reward bundling condition were concurrent chains with fixed delay intervals, fixed inter-trial intervals (ITIs), and rewards differing in value (i.e. 10 or 50 points). Preference was measured as percentage of choice. Participants encountered five phases: 1) pretraining, 2) small immediate vs. large immediate, 3) small immediate vs. large delay (i.e. unbundled), 4) reward bundling, and 5) unbundled (post-test).

Dependent Measures

The primary dependent variable was choice responding. Specifically, participants' preference for self-control (large delayed reinforcement) or impulsive (small immediate reinforcement) choice alternatives. Preference was assessed by measurement of responses allocated to larger-later reinforcement or smaller-sooner options.

Measurement

Data collection

Data was collected using the Pygame software designed for the purpose of this research, as well as the Zoom teleconferencing call recording function. The Pygame program recorded the points, duration, and ITI of every trial as well as participant choice for alternatives. The program was also responsible for tracking whether participants had reached criteria to repeat or move on to the next condition. The teleconferencing sessions were recorded using the Zoom software. Sessions occurred once a day, up to three times per week based on availability of the participant. Each participant completed trial blocks in a session according to their respective behavior throughout the study.

Independent Measures

The primary independent variable was the reward bundling procedure. The Pygame software used in this investigation was designed to offer bundled choice alternatives with delays based on results of the review by Staubitz et al. (2018), trial and delay alternatives identified in the self-control training literature (e,g. Dixon & Cummings, 2001), and on results of data collected during beta testing for the development of the program in which school-aged children with various diagnoses engaged with the protocol.

Procedures

General

Participants "played" through a series of choice paradigms using the Pygame program developed for this research project. In order to create a visually familiar interface that appeals to children, the program was designed to mimic the qualities of a simple video or computer game. Visual and temporal cues were included to the minimum extent possible to orient the user to a novel system and facilitate attending to the interface without having to offer programmed reinforcement from external sources. All of the stimuli listed below are present throughout the game so as to minimize potential confounds to the procedure. Similar to changing levels in a video game, each change in condition was signaled by a change in the background image of the program. The images are vector illustrations of similarly pixelated and vibrant landscapes. If the user repeated trials in a condition (discussed in the conditions below), the image remained the same. To signal to the user that the game was not malfunctioning despite the disappearance of previous stimuli on the screen, a black and white vector illustration of an analogue alarm clock with no arms appeared in the upper right-hand corner of the screen at the onset of all delay intervals. The presence of the clock did not delineate the duration of the interval nor offer any indication of time passing. The total score was visible in the upper left corner of the screen. Lastly, a vector illustration of a progress bar was present in the upper right corner of the screen beneath the score to signal percentage of game completion.

Prior to starting the program, the experimenter instructed the participant to collect as many points as they could, and encouraged participants to ask questions if they did not understand the game. The experimenter only answered questions about how to use the interface. The game opened to a screen providing written instructions of how to operate the program using the keyboard including (1) *Use ‘<-‘ and ‘->’ to move* (i.e. left and right arrow keys); (2) *Press spacebar to fire*; and 3) *Press ‘s’ to start the game*. The experimenter also read these directions to the participants. When the participant pressed ‘s’ to start the game, the pretraining condition was initiated. In order to orient the user to the game interface, the participants first encountered ten balloons of various colors, sizes, and point values (1, 10, or 50 points) similar, but not identical to what appears in future conditions. In all trials, the balloons appeared in a random position on the screen, and in forced-choice trials the balloons appear in random order with a counterbalancing component. The participants used the arrow keys to move the slingshot side to side on the screen and line up a vertical shot towards a balloon. When the spacebar was pressed, a rock was thrown into the air, and a balloon was popped. The points were flashed in the middle of the screen where the balloon was popped, and were added to a running total score in the upper left corner. One less balloon appeared in a random position on the screen each trial for a total of 10 trials. Once the participant demonstrated appropriate use of the keys, he or she continued to the next condition.

The experiment included five conditions. First, a pretest of impulsive choice was conducted in Choice Baseline 1 by offering a small immediate reinforcer versus a large delayed reinforcer.

These unbundled trials were implemented until the participate showed clear preference for an alternative during five out of six free-choice trials. If the participant demonstrated clear preference for the small-immediate reinforcer during five of six consecutive free-choice trials, the Choice Baseline 2 was initiated. Choice Baseline 2 was conducted to confirm that participants would discriminate between point values and choose the larger reinforcer option when both the large and small options were delivered immediately. Once the participant demonstrated clear preference for the large immediate alternative, the reward bundling condition was initiated. Then, during reward bundling, the participant was presented with choices between large-delayed bundled reinforcement and small-immediate bundled reinforcement choice options. When preference was demonstrated four out of five or five consecutive trials of free-choice trials during the bundled condition, the post-test of unbundled rewards condition (similar to Choice Baseline 1) was reintroduced to determine whether participants maintained their preferences following the reward bundling procedure. Session were performed at least once per week based on participant availability. Each condition is described in further detail below.

Baseline

Choice Baseline 1 (Unbundled Rewards). The participants chose between a small reinforcer (10 points) available immediately versus a large reinforcer (50 points) following a 16-second delay. The session, or trial block, began with four forced-choice trials (two trials with each reinforcer option) in which only one of the choice alternatives were available on the screen. Following the four forced-choice trials, the participants selected between the small immediate reinforcer and the large delayed reinforcer in five free-choice trials in which one of each of the alternatives were presented on the screen at the same time.

If the participant selected the LL alternative for five consecutive trials or five out of six total trials (i.e. indicating preference for self-control), the participant was excluded from participating in the study. If the participant selected the SS alternative for five consecutive trials or five out of six trials, Choice Baseline 2 condition was initiated. If the participant did not show preference for either of the alternatives by selecting them more than one time each, the condition was repeated beginning with the four forced-choice trials. The program automatically moved the participant to the appropriate condition based on his/her selections during this phase, Choice Baseline 2, and the bundled-reward phase. LL delay duration was divided by four to determine the inter-trial interval (ITI), which is the amount of time between the consumption of the SS points and the beginning of the next trial. There was a 1 s ITI following consumption of the LL points. An ITI was utilized in order to avoid continuous responding for the SS reward (i.e. maximization of reinforcement by consistently choosing the SS option).

Choice Baseline 2. The purpose of this condition was to confirm that the participant could discriminate between point values and would select the alternative that maximized reinforcement. This phase began with four forced-choice trials followed by five free-choice trials with both the small reward (10 points) and the large reward (50 points) available immediately. In the forced-choice trials, only one balloon was available to pop, and balloon order and position on the screen were randomized with two presentations of each balloon in alternating order (i.e. two opportunities to select the small immediate, and two opportunities to select the large immediate). Following the forced-choice trials were six free-choice trials in which one of each balloon choice alternatives were presented at the same time. When the participant showed preference for the large immediate reward during five out of six free-choice trials, reward bundling was initiated. If the participant did not show exclusive or near exclusive preference for the large immediate reward, the forced-and free-choice trial block sequence was repeated. The experimenter took notes by hand along with the program calculations to determine whether the participant reached the criteria.

Bundled Rewards. Procedures for the bundled condition were identical to the previous choice conditions with regard to the four forced- and free-choice trials scheduled for each trial block. During the forced-choice trials, a bundle of four SS or four LL balloons appeared on the screen, and during the free-choice trials a bundle of four SS and a bundle of four LL balloons appeared on the screen at the same time. A "bundle" was characterized by four consecutive presentations and deliveries of the initially chosen alternative followed by its corresponding delay and reward. Specifically, when the participant chose the LL delay option at the onset of the free-choice trial by shooting any of the eight large balloons, the following occurred: (a) all balloons disappeared from the screen, (b) the 16-second delay was implemented followed by the delivery of points, (c) three large balloons appeared and the participant selected one, (d) the delay was implemented followed by the delivery of points, (e) two large balloons appeared and the participant selected one, (f) the delay was implemented followed by the delivery of points, (g) one large balloon appeared and the participant selected it, (h) the delay was implemented followed by the delivery of points, and (i) a new trial initiated with the two bundle alternatives on the screen (i.e., four LL balloons and four SS balloons). When the participant chose the SS option at the onset of the free-choice trial, the procedure was identical to the LL option with the following exceptions that occurred: (a) following the SS bundle, a 4-second ITI occurred, which is one fourth the LL delay. There was no ITI following the LL bundle. If the participant showed stable responding by selecting four or five of the same alternative out of five trials, the next phase (i.e., Post-test of unbundled rewards) was initiated. If stable responding was not reached, the participant repeated the condition by starting again with four forced-choice trials followed by five free-choice trials in follow-up trial sessions. In order to keep sessions reasonably short, the first session ended with completion of one trial block in the reward bundling condition (regardless of participant selections). Follow up sessions began at the start of the reward bundling condition with forced-choice trials followed by free-choice trials, and were capped at approximately 30 minutes with the researcher stopping the participant at the end of a trial block.

Post-test of Unbundled Rewards. The final condition was identical to the choice baseline 2 (Unbundled) condition except that there will be no forced-choice trials, and there were ten free-choice trials of a large delayed balloon (50 points) versus small immediate balloon (10 points) to pop. The purpose of this condition was to determine whether biased responding for the LL alternative shown in the reward bundling procedure persisted when offered alternatives in a single-reward choice arrangement similar to the pre-test of impulsive choice.

CHAPTER 4: Results

Choice Baseline 1: Pre-test of Impulsive Choice

Results for Daryll are displayed in Figure 1 and Figure 4. Daryll exhibited exclusive preference for the SS reward upon completion of the second trial block. In the first trial block, he did not show preference for either alternative, selecting the SS reward and LL reward 50% of the time respectively. In the second trial block, he chose the SS reward in 100% of trials. Results for Martin are displayed in Figure 2 and Figure 5. Martin showed near exclusive preference for the SS reward upon completion of the first trial block, selecting the SS reward at 83% (or five out of six trials). His single response for the LL reward occurred early in the trial block as his second of six responses. Results for Scotty are displayed in Figure 3 and Figure 6. Scotty showed near exclusive preference for the SS reward upon completion of the second trial block. In the first trial block, he preferred the LL reward for 66% of trials, then in the second trial block preferred the SS reward for 83% of trials. Similar to Martin, his single preference for the LL reward in the second trial block occurred second in six trials, with clear preference for the SS reward in the following four consecutive trials.

Choice Baseline 2: No Delays

Daryll initially showed no preference by allocating 50% of choice responding to each alternative during the first trial block of the five completed in total. In the second and third trial blocks he selected the large-immediate alternative 33% of the time, then in the fourth trial block 66% of the time, and in the fifth and final block he selected the large-immediate alternative during 100% of trials. Martin showed near exclusive preference for the large-immediate reward during the first trial block. Scotty completed a total of six trial blocks in this condition. Initially, he preferred the small-immediate alternative in 66% of trials during the first trial block; then he showed preference for the LL reward for 63% of trials in the middle four trial blocks; and lastly, 83%, or near exclusive preference for the large-immediate reward during the final trial block.

Reward Bundling

Total trials completed by each participant varied based on how many they required to demonstrate exclusive preference for an alternative. In the first of six total trial blocks, each consisting of five trials, in the Reward Bundling phase, Daryll preferred the SS reward during 60% of opportunities. During the next four trial blocks, he selected the LL for 60% of opportunities; then during the sixth and final trial block he selected the LL reward during 100% of trials, exhibiting exclusive preference for that alternative. Overall, he preferred the LL reward during 66% of reward bundling trials. Daryll completed all conditions in six sessions over a span of twelve days.

During the first of five total trial blocks for Martin, he preferred the SS reward during 60% of the five trials. During the next three trial blocks, he selected 60% in favor of the LL reward. In the fifth and final trial block he showed exclusive preference for the LL reward by selecting it in 100% of opportunities. Martin preferred the LL reward for 64% of total trials during this phase. He completed all conditions in four sessions over a span of twelve days.

Scotty completed the Reward Bundling phase in one trial block. He selected the LL reward for 4 out of 5, or 80% of the trials. All conditions were completed in a single day session.

Post-test of Unbundled Rewards

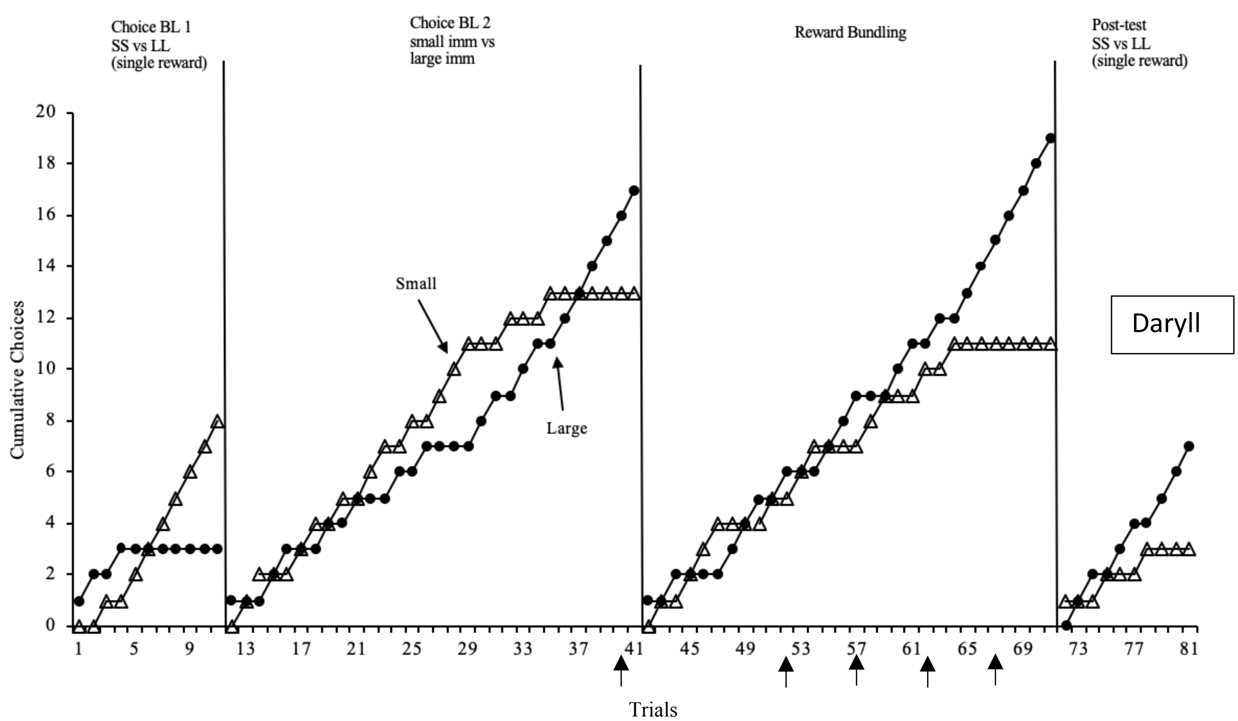
During the post-test of impulsive choice, participants encountered the same contingency as in choice baseline 1 of SS versus LL rewards, but under a different set of stimuli and different number of trials. This phase included a new background on the screen, and ten free-choice trials and no forced-choice trials at the start of the phase. Two of the three participants maintained their biased choice for the LL reward, and one reversed choice for the SS reward. Daryll and Martin both selected the LL reward during 70% of opportunities. Scotty selected the LL reward during 40% of opportunities, however he stated that he was selecting the SS reward because he thought it was worth 100 points instead of the previous 10 points.

Summary

In summary, all three participants showed higher rates of responding for the self-control alternative in the reward bundling condition than in the baseline conditions. The preference for the self-control alternative over the impulsive alternative maintained in the post-test of impulsive choice for two out of three of the participants.

Figure 1

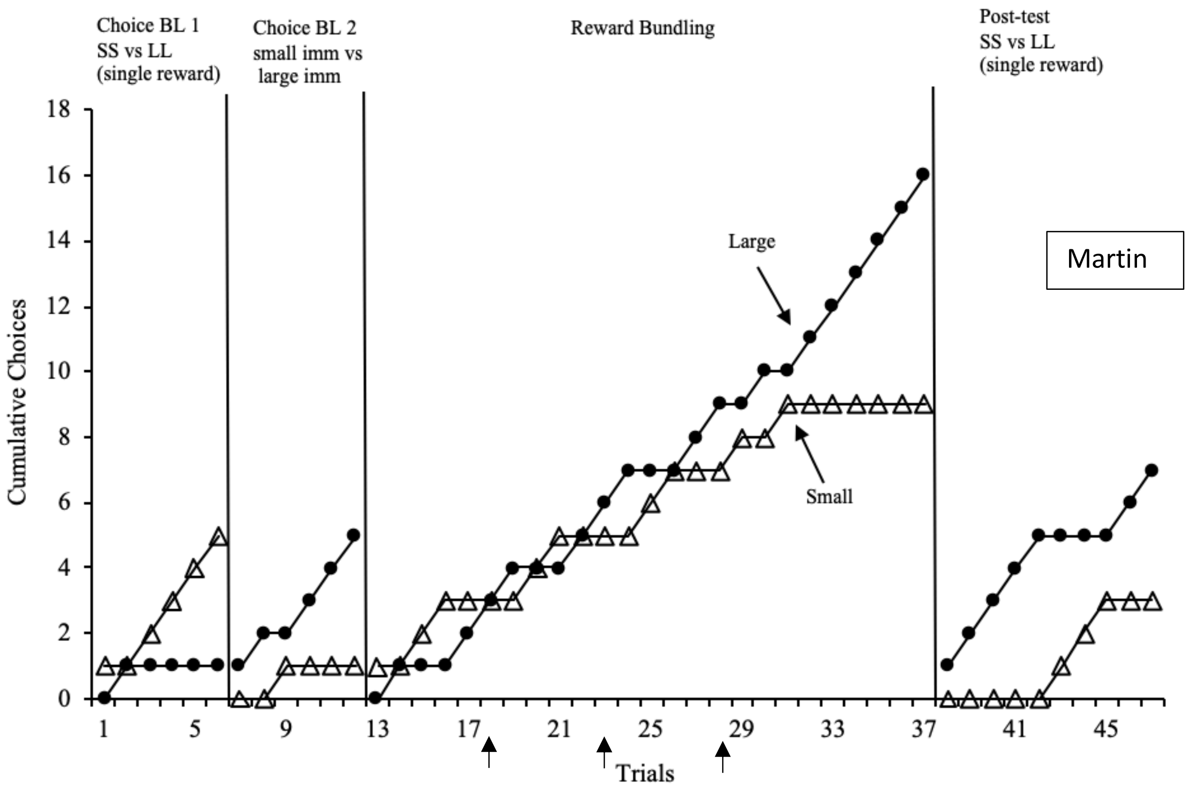
Cumulative Choices for Participant 1



Note. Cumulative choices for the small and large rewards across all conditions for Daryll. BL= baseline; SS=smaller-sooner; LL=larger-later; imm=immediate. Arrows under x-axis indicate new session date.

Figure 2

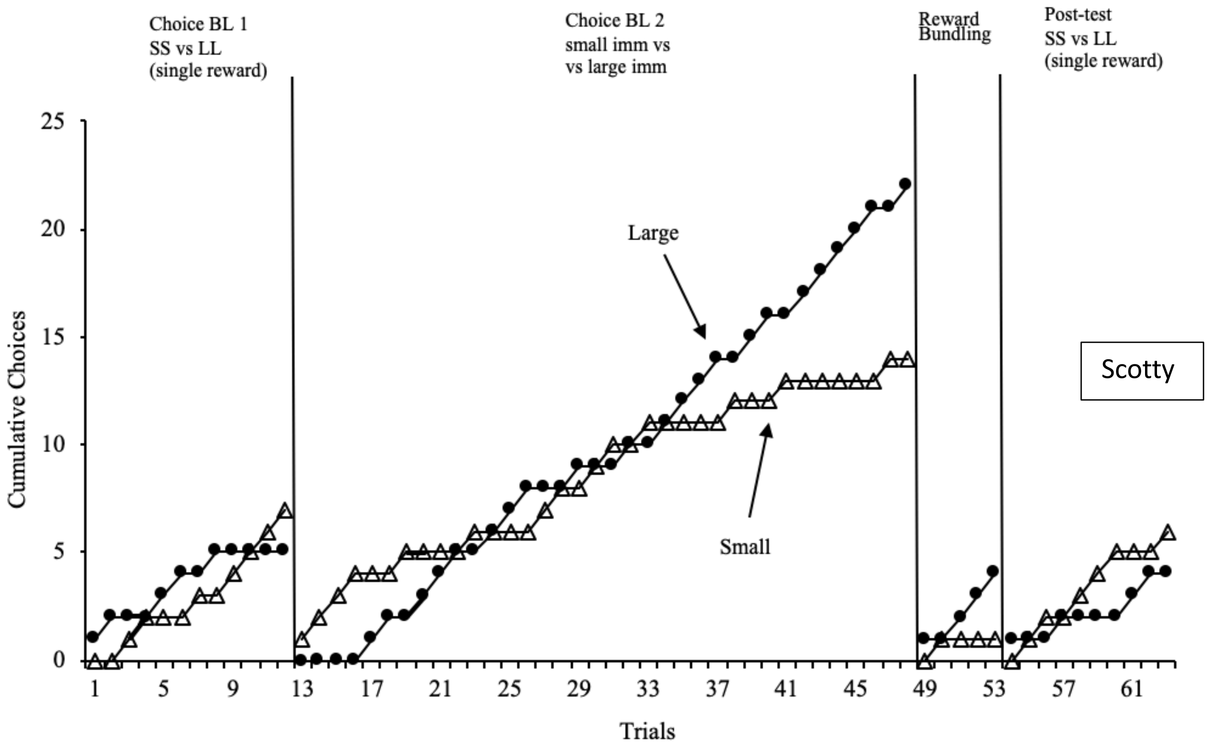
Cumulative Choices for Participant 2



Note. Cumulative choices for the small and large rewards across all conditions for Martin. BL= baseline; SS=smaller-sooner; LL=larger-later; imm=immediate. Arrows under x-axis indicate new session date.

Figure 3

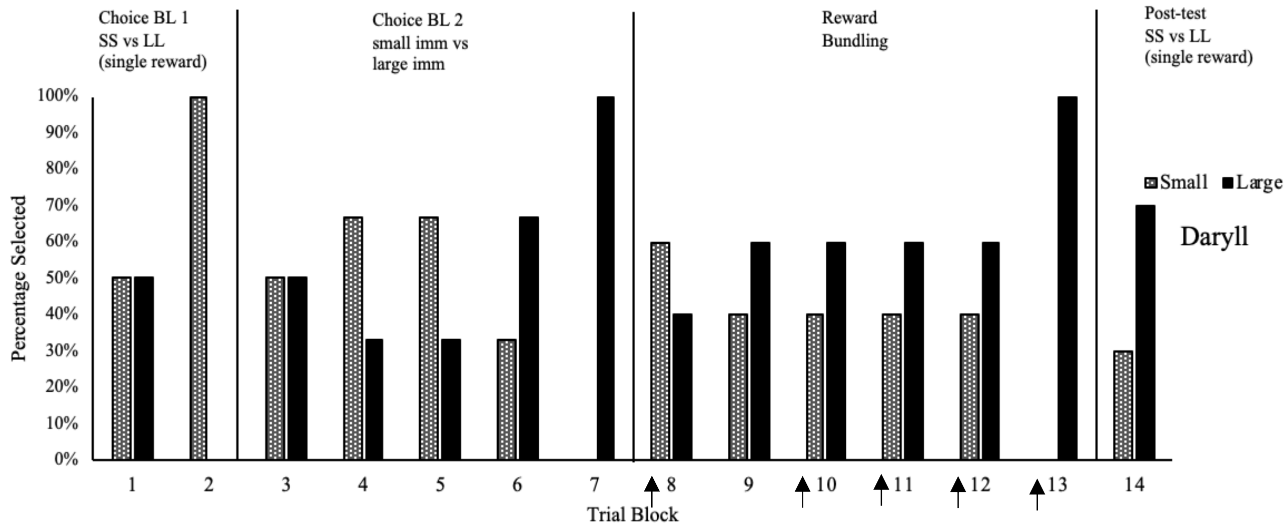
Cumulative Choices for Participant 3



. *Note*. Cumulative choices for the small and large rewards across all conditions for Scotty. BL= baseline; SS=smaller-sooner; LL=larger-later; imm=immediate.

Figure 4

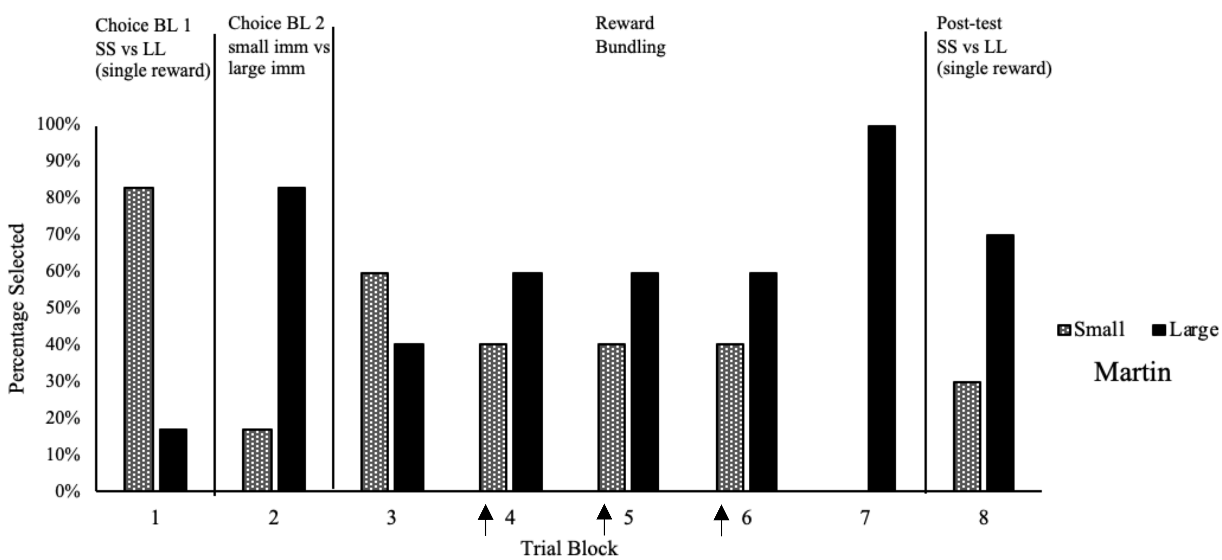
Selection Percentage by Trial Block for Participant 1



Note. Percentage of choices for the small and large rewards per trial block in each condition for Daryll. BL= baseline; SS=smaller-sooner; LL=larger-later; imm=immediate. Arrows under x-axis indicate new session date.

Figure 5

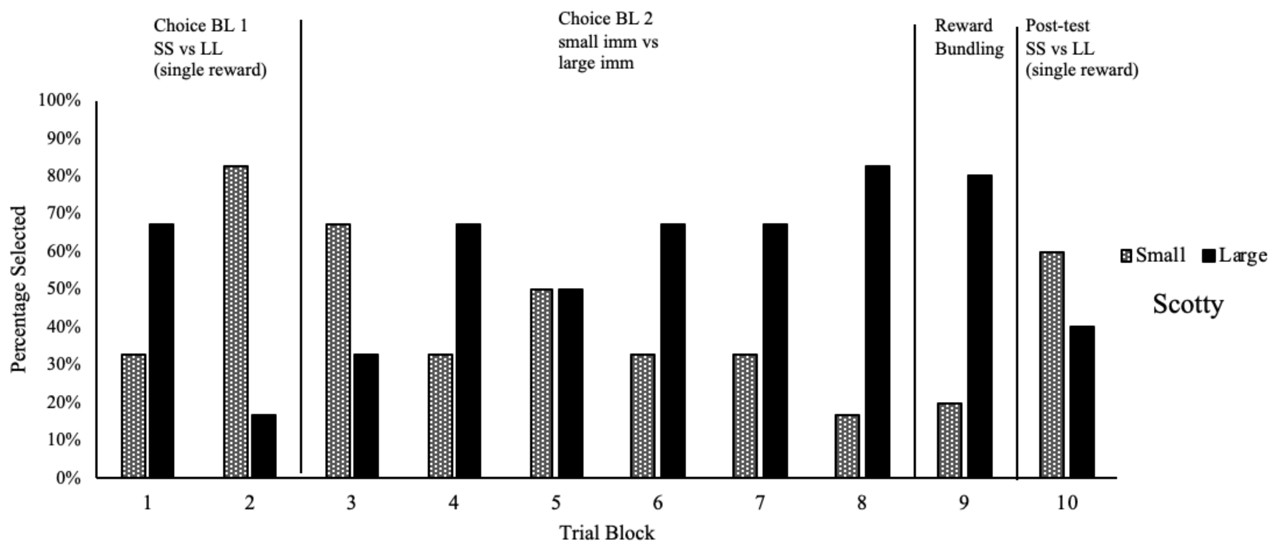
Selection Percentage by Trial Block for Participant 2.



Note. Percentage of choices for the small and large rewards per trial block in each condition for Martin. BL= baseline; SS=smaller-sooner; LL=larger-later; imm=immediate. Arrows under x-axis indicate new session date.

Figure 6

Selection Percentage by Trial Block for Participant 3



Note. Percentage of choices for the small and large rewards per trial block in each condition for Scotty. BL= baseline; SS=smaller-sooner; LL=larger-later; imm=immediate.

CHAPTER 5: Discussion

Results

The results of the current study showed that self-control choice responding can be increased in participants who initially opted for the more impulsive alternative. The data suggest that presenting the delay and reward alternatives as a reward bundle is capable of bringing about this shift in preference for young individuals previously identified as impulsive. These results further support those by Ainslie (1975), Ainslie and Monterosso (2003), Hofmeyr et al. (2011), and Kirby and Guastello (2001), who also showed that exposure to reward bundling may result in increases in self-control. The current study was unique in its incorporation of a game-like computer program, as well as the utilization of a novel clinical population to investigate the principles of operant choice and self-control.

In order to translate the previous bundling literature to our applied population, we selectively incorporated methods from the self-control training literature that resolved issues of accessibility while maintaining experimental control. First, previous studies evaluating reward bundling and human participants utilized computer-based auction comparisons with written instructions requiring language skills exceeding those of our target population (Kirby & Guastello, 2001; Kirby, 2006; Bialaszek & Ostaszewski, 2011; and Hofmeyr et al., 2011). This study differs by using a computer program that instead evaluates comparisons and stimuli that are accessible to young children and non-readers. Specifically, this experiment utilized delay durations and reward values established from: (1) the results of a review on delay-discounting in children (Staubitz et al., 2018) that determined delays should be under 30 s; (2) an average number of trials and delay alternatives taken from numerous studies in the self-control training literature (e.g. Dixon & Cummings, 2001); and (3) results from beta testing with children of similar characteristics prior to the study. Another way we incorporated self-control training methods to translate the procedure from the basic model is the utilization of two choice baselines. Rather than estimating discounting rates from inverted second-price auctions (e.g. Kirby & Guastello, 2001), the present experiment utilized choice baselines to, (1) confirm impulsivity via preference for SS over the LL rewards, then (2) confirm that the participant could discriminate between the values and would prefer the option that maximized reinforcement (Dixon & Cummings, 2001) prior to implementing the reward bundling procedure. These measures extend the previous literature by providing a means for translating mechanisms from the basic reward bundling literature to experiments involving applied populations.

Given that this was the first translational study to use the reward bundling procedure with children from a clinically relevant population, one main objective was to show differentiated results within a novel experimental model. One consideration was that experience with both the small and large reward outcomes is central to identifying which alternative is optimal under a given set of conditions (Young et al, 2013). The forced-choice trials exist to expose the subjects to the contingencies of each phase of the procedure and ensure sampling of the alternatives to confirm that choice is not arbitrary prior to test trials. The results reveal that all three participants who completed the study gradually switched preference from the impulsive to the self-control option over consecutive trial blocks. Therefore, it is possible to conclude that differentiation was achieved by implementing procedures from previous research in reward bundling which demonstrated that forced-choice trials allow sufficient sampling of the alternatives in the absence of specific instructions about the outcome of their selections (e.g. Ainslie & Monterosso, 2003; Brunner, 1999; Shull et al., 1990; Stein et al., 2013).

Another potential explanation for achieving differentiation in a novel model is the incorporation of relevant stimuli. The current arrangement was designed for participants to complete the entire game independent of outside instructions and without instructions that biased responding for one alternative over another. The only external directions provided were brief instructions prior to the start that they would be playing a video game with the goal of getting as many points as they could, and on how to use the controls. All other information on how to behave was communicated by the presence of descriptive stimuli.

There were a couple of ways in which our data suggest that we included relevant stimuli that functioned to inform the participants on the experimental arrangement without biasing response allocation. The first was embedding the image of an analogue clock with no arms at the onset of the delay, to signal that a planned consequence was occurring, without signaling to the participants how long they would be required to wait to gain access to the LL reward. In the first trial in which the clock appeared, each participant tried clicking it multiple times, but that behavior quickly extinguished in the absence of reinforcement, and all three participants eventually stated their own version of "I have to wait" at the presence of the clock and did not engage in clicking on the screen, nor did they avert attention from the activity. Furthermore, all of the participants conformed to the contingencies outlined in each condition, without displaying what could be identified as erratic or arbitrary behavior, so it is reasonable to conclude that the combination of stimuli sufficiently imitated a typical video game structure, and took on discriminative properties.

Limitations

The first limitation to highlight is that limited instruction on how to interact with the choice alternatives may not imitate real-life situations of choice, such as verbal and physical cues that often occur in the natural setting. For instance, the current arrangement did not include any external programmed rewards for tolerating delays, only points summed for a total score like that which occurs in a typical computer game. Previous research has validated that hypothetical reward and delay combinations provide similarly efficacious results to real rewards and delays (e.g. Odum et al., 2002). There is also a growing body of evidence in the video-game-based choice literature providing a basis for comparison with results of the current study (e.g. Rung & Young, 2015). However, it might be argued that digital points carry less value or are less tangible than receiving an edible reinforcer or access to a preferred item, especially with consideration of our target population. Therefore, it is difficult to draw firm conclusions about comparing the consequence of a real-world delay prior to receipt of this type of reward when examining preference of young people with disabilities.

Other potential limitations regard participants and setting. Inclusion criteria for participation was kept purposefully minimal to encourage a variety of characteristics under study, with screening occurring via choice baselines. While the eight original participants included three females and five males with varying diagnoses, only results for three males who completed all conditions are examined. Limited conclusions may be made about the generality of the results of the study based on participant characteristics. Further, this experiment was performed during the COVID-19 quarantine period in which students began receiving educational services including school and outside therapies via telehealth, which was distinct from their typical learning environments. It is unclear how this may have affected the results of the study. One way the experiment may have been affected is fatigue. While steps were taken to minimize this by: (1) never running more than one reward bundling trial block per session; (2) never running any session more than approximately 30 min; and (3) by visually inspecting the data for within-day patterns of responding, it is possible that this may still have occurred due to the extensive increase in time spent learning on the computer in a day.

Lastly, it is possible that Scotty completing the conditions in a single session resulted in insufficient exposure to the contingencies, causing a disrupted pattern of preference in the post-test condition that did not include forced-choice trials. Scotty exhibited preference for the SS reward in the post-test, immediately after demonstrating preference for the LL reward in the fewest number of reward bundling trials compared with the other participants. During the post-test, he stated that he was selecting the SS reward because he thought the value of the balloon was worth 100 points, rather than the actual 10 points. A video-game-based escalating interest task by Young et al. (2013), found sensitivity to a new set of conditions was clearly influenced by previously experienced conditions. In the case of the current study, Scotty's sensitivity may have been to Choice Baseline 2 in which neither the small or large rewards followed a delay. He completed 36 trials in this condition, compared with 17 trials in the small immediate versus large delay conditions (e.g. Choice Baseline 1 and Reward Bundling) prior to performing the post-test.

Future Directions

An essential objective of translational studies on choice responding is to determine the extent to which the variables that affect response allocation in basic experiments with nonhumans produce similar effects with humans under more natural conditions. There were a number of variables from the previous literature not applied to this arrangement of the reward bundling procedure. Therefore, it is reasonable to posit that future studies will afford researchers the opportunity to demonstrate valuable outcomes by further utilizing combinations of variables that result in effective treatment opportunities.

Basic

Basic researchers could answer further questions not amenable to applied settings, such as underlying mechanisms of the results of the current investigation. For example, these could further evaluate: (1) magnitude effects; (2) reinforcer quality; (3) delay durations; (4) forced exposure and instructions; and (5) establishing individual valuations of rewards across various delays. Further research that investigates the role of these components on choice behavior under similar methodologies could build a platform for understanding ways to apply this intervention and give applied researchers ideas of how to improve those interventions by standing on a strong foundation of basic behavioral findings.

Translational

Human operant labs provide a suitable environment to perform controlled studies that integrate uniquely human qualities such as preference. Preference for reward alternatives is a difficult concept to translate from animals, so investigations that assess preference for a wide variety of rewards and durations and their effects on self-control using humans without disabilities could offer valuable findings. The current study's computer-based design provides a viable template for translational studies investigating reward bundling in non-clinical populations. There is limited but promising research in reward bundling on how the magnitude of the reward may influence preference for different delay durations (e.g. Stein et al., 2013). Future studies could benefit from exploring the mechanisms related to magnitude under similar experimental designs to determine the effect of reward size in reward bundling.

Applied

A potentially valuable extension of the current investigation would be to assess conditions needed for generalization of videogame-based results to the natural environment.

This could include fading descriptive stimuli, offering forced exposures to other rewards, or examining utility of further imbedding procedures into evidence-based interventions such as rule-governed behaviors with contingency-specifying instructions (e.g. Falcomata et al., 2008). Further, applied researchers could utilize this study's design to offer insights that might affect impulsive responding outcomes such as challenging behavior (e.g. Vollmer et al., 1999). This investigation could have potentially wide applicability considering the broad use of self-control training interventions as a treatment for impulsive behavior for individuals with disabilities. Lastly, further research is needed to provide information on the longevity of results for self-control using reward bundling. Early results from previous studies (Rung & Madden, 2018), as well as results from the current experiment, suggest potential for continued preference for selecting the self-control alternative even after treatment is withdrawn.

Conclusions

The results of the current investigation extend the self-control literature, building on previous knowledge of reward bundling while offering ideas for future studies along the research continuum (i.e., basic, translational, applied). Continued collaboration and communication among researchers will further help to move questions and answers into the hands of practitioners and caregivers in an efficient way, and result in more durable interventions that offer lasting change in the treatment of impulsive behavior in individuals with disabilities.

APPENDIX

Table 1

Experimental Question and Results of the Reviewed Reward Bundling Studies

Study	Experimental Question	Participants	Results
Ainslie & Monterosso (2003)	Using an ABBA design to compare standalone choices to bundled choices, does the bundling effect occur in non-primate species?	8 rats	• Bundling pairs of SS-LL choices results in greater preference for LLs than when choices are made singly.
Bialaszek & Ostaszewski (2011)	Is the magnitude effect present in cases where hypothetical delayed sequences of monetary rewards are discounted?	54 graduate students (23 males and 31 females)	• Sequences of large rewards are discounted less steeply than are sequences of small rewards. However, the possibility of choosing a single large reward can be more tempting than obtaining the same amount spread over an extended period of time.
Brunner (1999)	Does the parallel discounting model accurately describe the sensitivity to the particular temporal arrangement when there is a greater number of rewards in a sequence?	8 rats	• In the three experiments, rats' preferences followed qualitative predictions of the parallel discounting model. • Preference was variable and close to indifference when value alternatives were similar. • In the condition in which the spacing between the six pellets was long, there was a preference for the two-pellet option.
Hofmeyr et al. (2011)	In a sequence of decisions involving hypothetical SS versus LL rewards, does suggesting or forcing smokers to make the decision for the series as a whole increase preference for the LL?	60 adults (30 smokers and 30 nonsmokers)	• Smokers increased preference for LL rewards when the bundled decisions were suggested and forced. • Sequences of larger rewards and forced choices were most effective in biasing preference for the LL reward.
Kirby (2006) Experiments 1 & 2	Using delayed cash rewards and restaurant gift cards in a computer-based auction procedure, will adults prefer the single rewards or	College students	• The present value of a sequence of delayed rewards is approximately the sum of the discounted values of the individual rewards in the sequence.

	sequences of those rewards? Are the results well-fitted to the parallel hyperbolic discounting model?		• Discounting of sequences was well fit to the hyperbolic discounting model.
Kirby & Guastello (2001)	Does linking a current choice with similar future choices increase self-control in individuals choosing between SS and LL amounts of money or food?	72 undergraduate students (45 women and 27 men)	• College students showed greater preference for LLs when they were bundled together than when they were chosen singly. • One third of participants preferred the LL reward in the free-linking condition, and all but one participant preferred the LL reward in the imposed-linking condition.
Mitchell & Rosenthal (2004)	Using an adjusting amount procedure, will rats choose the immediate or the delayed food alternative? Will they select the SS or the LL when the rewards are presented in a bundle rather than singly?	12 rats	• The presence of multiple delayed rewards increases the subjective value of the delayed option. • Increases in these indifference points can be fitted to a parallel model of discounting.
Shull et al. (1990)	Using forced-choice trials and terminal link chain schedules, will choice favor the terminal link with the higher sum of the immediacies and will delays in the initial link affect the value of the sum?	3 pigeons	• The pigeons' choices consistently favored the smaller option when the delay to the first delivery was 20% of the delay to the first delivery in the larger terminal link. • The pigeons' choices generally favored the larger option when the delay was increased to 80%.
Stein et al. (2013)	Using a between subjects design, does exposure different sized bundles effect choice, and does reward bundling increase self-control for unbundled reward?	24 rats	• Rats in the bundle-size 9 group showed significantly greater larger-later reward preference across a range of delays then rats in the bundle-sizes of 1 (i.e. no bundling) or 3. • When choice for unbundled rewards was assessed following the reward bundling phase, rats in bundle-size 9 showed a significant increase in LL reward preference compared to a pre-test.

Note. SS= Smaller-Sooner; LL= Larger-Later

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